Optimal Power Flow in the presence of SVC using Imperialistic Competitive Algorithm

[1]G. Nageswara Reddy,*, [2]S.S.Dash, [3]S.Sivanagaraju, and [4]Ch.V.Suresh

[1]Electrical and Electronics Engineering Dept, Yogi Vemana Univ, A.P., India,
[2]Electrical and Electronics Engineering Dept, SRM Univ, Tamilnadu, India
[3,4]Electrical and Electronics Engineering Dept, JNTU Kakinada, A.P., India,
Email: [1]gnageswarareddy@gmail.com, [2]munu_dash_2k@yahoo.com, [3]venkatasuresh3@gmail.com

Abstract—The latest development in Flexible AC Transmission System Controllers (FACTS) upturns the technological developments towards enhancing the system performance. Improving voltage at system buses using Static VAr Compensator (SVC) is studied by placing this device in an optimal location. The paper presents a methodology to solve the optimal power flow problem with highly convex, non-linear non-convex cost function and system bus voltage deviations as objectives and is solved while satisfying equality, in-equality constraints. Later optimal location of SVC is identified to enhance the bus voltages. The single objective optimization problems are optimized using Imperialistic Competitive Algorithm (ICA). The efficacy of the proposed method is tested on IEEE-14 bus system. The validation of the proposed method is also compared with the existing methods.

Keywords—Optimal power flow, Imperialistic competitive algorithm, ramp-rate limits, SVC, optimal location.

I. INTRODUCTION

The operation of an electric power system is a complex one due to its nonlinear and computational difficulties. One task of operating a power system economically and securely is optimal scheduling, commonly referred to as the Optimal Power Flow (OPF) problem. In recent years, many Heuristic Algorithms, such as Genetic Algorithms (GA) [1, 2] and Evolutionary Programming [3, 4], Simulated Annealing [5], Particle Swarm Optimization [6], Chaos Optimization Algorithm [7], Tabu Search have been proposed for solving the OPF problem, without any restrictions on the shape of the cost curves.

In recent years, greater demands have been placed on the transmission network, and these demands will continue to increase because of the increasing number of non-utility generators and heightened competition among the utilities themselves. Optimal allocation method for static VAr compensator (SVC) has been proposed in [8]. Generally, FACTS devices are able to relieve congestions and decrease power losses as well as to reduce load shedding and generation re-scheduling [9], which may significantly contribute to decreasing annual cost of power system operation. By extending the methods in [10, 11], and [12], the proposed method accurately evaluates the annual cost and benefits obtainable by FACTS installation by formulating a large scale optimization problem that contains power flow analysis for a large number of system states representing annual power system operations.

This paper mainly concentrates on certain power system issues like optimal power flow and effect of ramp-rate constraints is analyzed in the presence of SVC. A methodology to install SVC in an optimal location is presented. The power system objectives such as generation fuel convex, non-convex costs and voltage deviations are optimized. The proposed OPF problem is solved while satisfying equality, in-equality constraints.

II. MATHEMATICAL MODELING OF SVC

It is a bank of three-phase static capacitors and/or inductors. Under heavy loading conditions, when positive VArs are needed, capacitor banks are needed, when negative VArs are needed, inductor banks are used. In this thesis SVC is modeled as an ideal reactive power injection at bus j shown in Fig.1.

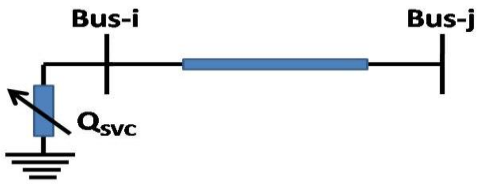

Fig.1. Mathematical power injection modeling of SVC

With reference to the Fig.1, the amount of reactive power injected into the bus j is given as follows.

$$Q_{SVC} = \frac{V_i^2}{X_{SVC}} \quad (1)$$

where V_i and V_j are voltage magnitudes at buses i and j and X_{SVC} is reactance of SVC converter transformer.

A. Optimal location

The SVC should be placed in an optimal location to maximize the benefit of the optimization problem. The following procedure is used to identify suitable SVC location and incorporation procedure.

Step1: Perform OPF with voltage deviation as an objective and without ramp-rate limits.

Step2: Obtain the system bus voltage magnitude values.

Step3: Identify the bus which has lowest voltage magnitude.

Step4: Place the SVC in that bus, within its operational limits as a shunt VAr injection.

Step5: Perform OPF for single and multi-objective problems with SVC.

The maximum and minimum injection limits of SVC are 100 and -100 MVAr respectively. After the optimal power flow is run, the corresponding VAR injection of SVC, which is also a control variable of objective function, is generated by the algorithm.

III. OPF PROBLEM FORMULATION

The OPF problem aims to minimize the power system objects by adjusting the system control variables while satisfying a set of operational constraints. Therefore, the OPF problem can be formulated as follows:

$$Minimize \quad J(x,u) \qquad (2)$$

Subjected to g(x,u)=0; h(x,u)≤0

where 'g' and 'h' are the equality and inequality constraints respectively and 'x' is a state vector of dependent variables such as slack bus active power generation ($P_{g,slack}$), load bus voltage magnitudes (V_L) and generator reactive power outputs (Q_G) and apparent power flow in lines (S_l) and 'u' is a control vector of independent variables such as generator active power output (P_G), generator voltages (V_G), transformer tap ratios (T) and reactive power output of VAr sources (Q_{sh}).

The state and control vectors can be mathematically expressed as

$$x^T = [P_{G_1}, V_{L_1}, \ldots, V_{L_{NL}}, Q_{G_1}, \ldots, Q_{G_{NG}}, S_{l_1}, \ldots, S_{l_{nl}}]$$
$$u^T = [P_{G_2}, \ldots, P_{G_{NG}}, V_{G_1}, \ldots, V_{G_{NG}}, Q_{sh_1}, \ldots, Q_{sh_{NC}}, T_1, \ldots, T_{NT}]$$

where, 'NL', 'NG', 'nl', 'NC' and 'NT' are the total number of load buses, generator buses, transmission lines, VAr sources and regulating transformers respectively.

A. Classical Smooth Fuel cost function

Generally, the fuel cost of a thermal generating unit is considered as a second order polynomial function (neglecting valve-point effects) and this is called classical smooth fuel cost function. It is represented as a quadratic equation given by

$$J_{cost} = FC = \sum_{i=1}^{NG} C_i(P_{G_i}) \qquad (3)$$

where, $C_i(P_{G_i}) = a_i P_{G_i}^2 + b_i P_{G_i} + c_i$

where, a_i, b_i, c_i are the fuel-cost coefficients of the i^{th} unit, 'FC' is the total generation cost, '$C_i(P_{G_i})$' is the fuel cost function of the i^{th} unit, 'P_{G_i}' is the power generated by the ith unit.

B. Voltage deviation

The voltage deviation at buses needs to be minimized to optimize the reactive power dispatch problem. With this the stability of the system will enhances and this can be expressed as

$$J_{vdev} = \sum_{i=1}^{N_{bus}} |V_i - V_i^{spe}| \qquad (4)$$

where, V_i is the voltage at bus-i, V_i^{spe} is the voltage set to be '1 p.u.' and NB is the total number of buses. The V_i^{spe} is taken as 1 p.u because while finding the p.u voltage the actual voltage is expressed in terms of base voltage. In general conditions the actual voltage won't exceed the base voltage.

C. Non-Smooth Fuel cost function

Typically, the valve point results in, as each steam valve starts to open, the ripples like in to take account for the valve – point effects, sinusoidal functions are added to the quadratic cost functions as follows.

$$J_{cost} = FC = \sum_{i=1}^{NG} C_i(P_{G_i}) \qquad (5)$$

where,

$$C_i(P_{G_i}) = a_i P_{G_i}^2 + b_i P_{G_i} + c_i + |e_i \times \sin(f_i \times (P_i^{min} - P_i))|$$

where, e_i and f_i are the fuel cost-coefficients of the i^{th} unit reflecting valve-point loading effects.

D. Constraints

The objective functions are subjected to the following equality, inequality and practical constraints.

1) Equality constraints

These constraints are typically power flow equations handled in Newton Raphson load flow.

$$P_{Gi} - P_{Di} - \sum_{j=1}^{N_{bus}} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i) = 0$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{N_{bus}} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) = 0$$

where, P_{Gi}, Q_{Gi} are the active and reactive power generations at i^th bus, P_{Di}, Q_{Di} are the active and reactive power demands at i^th bus, N_{bus} is number of buses, $|V_i|$,$|V_j|$ are the voltage magnitudes of i^th and j^th bus respectively, δ_i,δ_j are the voltage angles at i^th and j^th bus respectively and $|Y_{ij}|$, θ_{ij} are the bus admittance magnitude and its angle between i^th and j^th buses.

2) In-equality Constraints

Generator bus voltage limits:

$$V_{G_i}^{min} \leq V_{G_i} \leq V_{G_i}^{max}; \quad \forall \;\; i \in NG$$

Active Power Generation limits:

$$P_{G_i}^{min} \leq P_{G_i} \leq P_{G_i}^{max}; \quad \forall \;\; i \in NG$$

Transformers tap setting limits:

$$T_i^{min} \leq T_i \leq T_i^{max}; \quad \forall \;\; i \in NT$$

Capacitor reactive power generation limits:

$$Q_{sh_i}^{min} \leq Q_{sh_i} \leq Q_{sh_i}^{max}; \quad \forall \;\; i \in NC$$

Transmission line flow limit:

$$S_{l_i} \leq S_{l_i}^{max}; \qquad i \in nl$$

Reactive Power Generation limits:

$$Q_{G_i}^{min} \leq Q_{G_i} \leq Q_{G_i}^{max}; \quad \forall \;\; i \in NG$$

Load bus voltage magnitude limits:

$$V_i^{min} \leq V_i \leq V_i^{max}; \quad \forall \;\; i \in NL$$

SVC device limits:

$$-100MVAr \leq Q_{SVC} \leq 100MVAr$$

Finally the above proposed problem is more generalized to solve in-equality constraints can be given as

$$J_{aug}(x,u) = J(x,u) + \lambda_p \left(P_{G_1} - P_{G_1}^{limit}\right)^2 + \lambda_v \sum_{m=1}^{NL} \left(V_m - V_m^{limit}\right)^2 + \lambda_q \sum_{m=1}^{NG} \left(Q_{G_m} - Q_{G_m}^{limit}\right)^2 + \lambda_s \sum_{m=1}^{nl} \left(S_{l_m} - S_{l_m}^{max}\right)^2$$

where, $\lambda_p, \lambda_v, \lambda_q, and\ \lambda_s$ are the penalty quotients having large positive value. The limit values are defined as

$$x^{limit} = \begin{cases} x^{max}; & x > x^{max} \\ x^{min}; & x < x^{min} \end{cases}$$

Here 'x' is the value of P_{G1}, V_m and Q_{Gm}.

E. Ramp-rate limits

The constraints of the ramp-rate limits, the operating limits of the generators are restricted to operate always between two adjacent periods forcibly. The ramp-rate constraints are

$$\max(P_{G_i}^{min}, P_i^0 - DR_i) \leq P_{G_i} \leq \min(P_{G_i}^{max}, P_i^0 + UR_i)$$

where, P_i^0 is i^th unit power generation at previous hour. DR_i and UR_i are the respective down and up ramp-rate limits of i^th unit.

IV. PROPOSED IMPERIALISTIC COMPETITIVE ALGORITHM

Imperialistic competitive algorithm [13] is inspired by the imperialistic competition in geo-political interactions between countries. Initially, countries for the considered control variables are generated. Out of which, some of them are best countries (lowest cost) treated as "imperialist" and the remaining are treated as "colonies". All colonies are moved towards their imperialists based on their powers. Here the power of each country is inversely proportional to its cost value. Finally, the "empires" are formulated by combining imperialists with the corresponding colonies.

After this, the assimilation policy is applied to move the empires towards their imperialist. Then power of each empire is calculated as the sum of the power of the imperialist and percentage of mean of power of its colonies. Then, all these empires participate in imperialistic competition and finally, the empire which has least power is eliminated from the system. The colonies will move towards their relevant imperialist and cause all the countries to converge to a state with single empire in the process.

The important steps in this algorithm are briefly discussed below:

a) Generating initial empires

Initially population is generated for all control variables as countries ($N_{country}$). For N-dimensional problem, the position of i^th country is defined as follows:

$$Country_i = [P_{G_2}, \ldots, P_{G_{NG}}, V_{G_1}, \ldots, V_{G_{NG}}, Q_{sh_1}, \ldots, Q_{sh_{NC}}, T_1, \ldots, T_{NT}]$$

The control variables corresponds to each population are updated in bus and line data then perform load flow and finally calculate the cost (C_i) of each country. Initialize the total number of imperialists (N_{imp}) and there by calculate the number of colonies (N_{col}=$N_{country}$-N_{imp}). To divide the colonies among imperialists proportionally, the normalized cost of all imperialists is calculated and based on this normalized powers are calculated [ref]. From this the number of colonies for n^{th} empire is evaluated. As the imperialists force to move the colonies towards them by applying attraction policy.

b) Moving colonies towards their imperialists

If a colony has best cost value than that of the imperialist, then exchange these colony and imperialist to continue this process in new location.

c) Calculation total power of an empire

The total power of an empire is the sum of the power of the imperialist and powers of the colonies.

d) Imperialistic competition

All these empires try to take the possession of colonies of other empires and try to control them. In this process, the power of the powerful empire increases where as the weak empire decreases. This competition is modeled by choosing some of the weakest colonies of the weakest empires and competition among all empires to possess these colonies. Then, total power of each empire is calculated.

e) Eliminating powerless empires

The powerless empires will collapse in the imperialistic competition. Different criteria can be defined for collapse mechanism. In this paper, an empire is assumed collapsed when it loses all of its colonies. Weak empires gradually decline in imperialistic competition and strong empires take the possession of their colonies. There are different conditions for declining an empire.

f) Stopping criteria

After some imperialistic competitions, all the empires except the most powerful one will collapse and all of the countries under their possession become colonies of this empire. All the colonies have the same positions and the same costs and there is no difference between the colonies and their imperialist. In such a case, the algorithm stops.

V. RESULTS AND ANALYSIS

In order to demonstrate the effectiveness and robustness of the proposed ICA method, IEEE-14 bus system is considered. The existing and proposed methodologies are implemented on a personal computer with Intel Core2Duo 1.18 GHz processor and 2 GB RAM. The input parameters of existing PSO method and the proposed ICA method for the two examples are given in Table.1.

Table.1. Input parameters for test examples

S. No	Optimization method	Parameters	Quantity
1	Existing Particle Swarm Optimization method (PSO)	Population size	100
		Number of generations	100
		Initial weight function, ω_{max}	0.9
		Final weight function, ω_{min}	0.4
		Acceleration coefficients C_1 and C_2	2
2	Proposed Imperialistic Competitive Algorithm (ICA)	Number of initial countries	1000
		Number of initial imperialists	8
		Number of decades	200
		Revolution rate	0.05
		Assimilation coefficient	0.2
		Zeta (ζ)	0.02
		Damp ratio	0.99
		Uniting threshold limit	0.02

An IEEE 14 [14] bus system has been considered in this example. The analysis is performed on the following objectives.

a) Convex fuel cost function
b) Voltage deviation
c) Non-convex fuel cost function

A. Convex fuel cost function

To validate the proposed method, the convex cost function given in Eqn.3 is optimized using existing PSO method and proposed method for 100 iterations with all control variables and the values are tabulated in Table.2. The convergence characteristics of these methods are shown in Fig.2.

From Table.2, it is observed that the OPF results obtained for the proposed method is close to the existing method. But, the total real power generation, real power loss and generation cost is less in the proposed method than PSO method. Further, the computing time in PSO method is 43.827 sec whereas in proposed method it is 25.128 sec, which is 18.699 sec less.

From Fig.2, the iterative process starts with minimum value and reaches the final best value in less no of iterations which shows convergence rate is fast for proposed method than existing method. This is because of best strings selected during the initialization process adopted in the proposed method and evolutionary operations are performed on these best strings. Further, the number of evolutionary operation is less for proposed method than PSO which leads reduction in the computing time.

Table.2 Comparison of OPF results for convex cost

S. No	Parameter		PSO	ICA
1	Real power generation (MW)	P_{G_1}	173.1518	171.2486
		P_{G_2}	45.97041	47.35682
		P_{G_3}	20.59935	20.71074
		P_{G_6}	16.29932	16.40793
		P_{G_8}	10.9280	10.81791
2	Generator voltages (p.u.)	V_{G_1}	1.10000	1.10000
		V_{G_2}	0.942171	1.08847
		V_{G_3}	0.998074	1.063891

		V_{G_6}	1.066812	1.076269
		V_{G_8}	0.937791	1.025176
3	Transformer tap setting (p.u.)	Tap_{4-7}	0.963731	0.959286
		Tap_{4-9}	0.939472	0.989937
		Tap_{5-6}	0.965703	1.001268
4	Shunt compensator (MVAr)	Q_{C_9}	27.20559	19.5346
5	Total real power generation (MW)		266.9489	266.542
6	Total real power loss (MW)		7.948857	7.541959
7	Total generation cost ($/h)		714.2431	713.0606
8	Computing time (sec)		43.827	25.128

Further the remaining objectives are optimized for the following three cases. The optimal location of SVC is identified by following the procedure given in section 2.1.

Case-1: Without SVC and without ramp-rate limits
Case-2: Without SVC and with ramp-rate limits
Case-3: With SVC and with ramp-rate limits

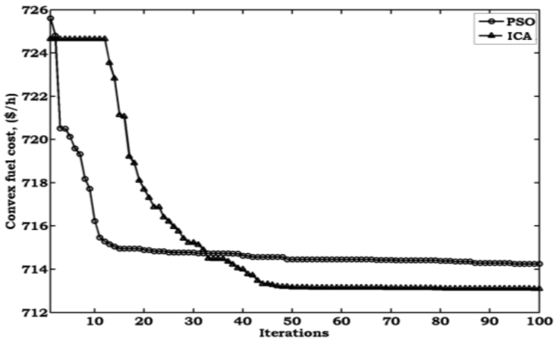

Fig.2 Comparison of convergence characteristics of convex fuel cost

B. Voltage deviation

The optimal solution of voltage deviation function given in Eqn.4 for Case-1 is obtained using ICA method for 100 iterations with all control variables and given in Table.3.

The voltage deviation of case 1 is shown in Fig.3. From this figure, it is identified that bus-14 has highest voltage deviation when compared to remaining buses. Hence, it is suitable to place SVC at bus-14. Further analysis is carried out by placing SVC at 14th bus.

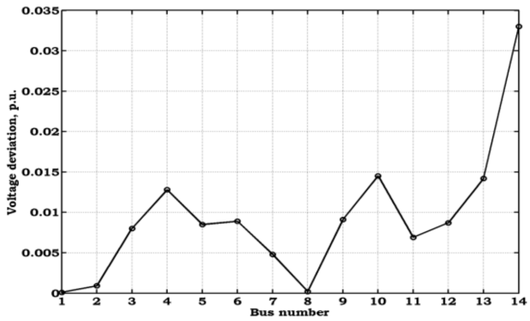

Fig.3 Variation of voltage deviation at system buses in Case-1

The optimal solution of voltage deviation function for the remaining 2 cases is obtained using ICA method and results of 3 cases are compared in Table.3. From this analysis, it is observed that, for the generator units with less Q generation will raise the voltage magnitudes at load ends.

Table.3 OPF results for voltage deviation objective for IEEE 14 bus system

S.No	Parameter		Case-1	Case-2	Case-3
1	Real power generation (MW)	P_{G_1}	70.4963	71.17291	65.71808
		P_{G_2}	98.58683	102.2939	100.4831
		P_{G_3}	31.12989	33.63586	36.50073
		P_{G_6}	30.74996	25.01218	24.97678
		P_{G_8}	32.44515	31.37095	35.41161
2	Generator voltages (p.u.)	V_{G_1}	0.999995	1.000379	1.000823
		V_{G_2}	1.009503	1.011411	1.013089
		V_{G_3}	1.000264	1.000149	1.000137
		V_{G_6}	1.023033	1.023341	1.037244
		V_{G_8}	0.999976	1.000094	1.00031
3	Transformer tap setting (p.u.)	Tap_{4-7}	0.99038	0.987219	0.991722
		Tap_{4-9}	0.96967	0.965658	0.963437
		Tap_{5-6}	0.989679	0.985391	0.987565
4	Shunt compensator (MVAr)	Q_{C_9}	20.60277	18.22207	18.86164
5	VAr injected by SVC (p.u)	Q_{SVC}	-	-	0.23584
5	Total real power generation (MW)		263.4081	263.4858	263.0903
6	Total real power loss (MW)		4.408128	4.48583	4.09031
7	Total non-convex cost ($/h)		991.3587	995.8712	1010
8	Voltage deviation (p.u)		0.06772	0.074424	0.070079

C. Non-Convex fuel cost function

The optimal solution of voltage deviation function given in Eqn.5 for Case-1 is obtained using ICA method for 100 iterations with all control variables and given in Table.4. The convergence characteristics comparison of the test system for three cases is shown in Fig.4.

Table.4 OPF results with Non-convex fuel cost function for IEEE 14 bus system

S.No	Parameter		Case-1	Case-2	Case-3
1	Real power generation (MW)	P_{G_1}	188.2752	184.3748	199.8063
		P_{G_2}	36.7087	39.41089	26.69307
		P_{G_3}	18.12252	20	20.00342
		P_{G_6}	15.21545	14.24215	14.53741
		P_{G_8}	9.194792	9.207223	7.130905
2	Generator voltages (p.u.)	V_{G_1}	1.099979	1.099985	1.1
		V_{G_2}	1.082525	1.087407	1.085792
		V_{G_3}	1.053027	1.062326	1.061259
		V_{G_6}	1.034745	1.052227	1.047469
		V_{G_8}	1.022529	1.005539	1.009638
3	Transformer tap setting (p.u.)	Tap_{4-7}	1.011496	0.997263	0.994125
		Tap_{4-9}	1.007052	0.975307	0.999172
		Tap_{5-6}	1.018495	1.026402	1.026323

4	Shunt compensator (MVAr)	Q_{C_9}	17.01556	16.71585	18.63038
5	VAr injected by SVC (p.u.)	Q_{SVC}	-	-	0.224325
6	Total real power generation (MW)		268.625	267.2351	268.1711
7	Total real power loss (MW)		8.516662	8.235059	9.17111
8	Total non-convex cost ($/h)		833.2859	835.683	829.1844
9	Voltage deviation (p.u)		0.497418	0.469	0.445183

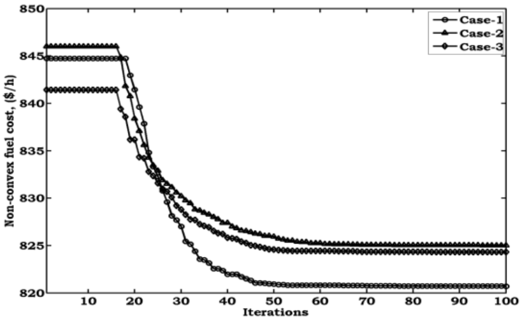

Fig.4 Convergence characteristics of non-convex fuel cost for 3 cases

From Fig.4, it is clear that in case-3 (with SVC), the iterative process starts with good initial value and reaches final best value in less number of iterations when compared to remaining cases.

VI. CONCLUSION

The ICA method has been successfully employed to solve the optimal power problem with generator constraints and valve point loading effect. Using this proposed method, the power system objectives like fuel cost and voltage deviation are optimized without and with ramp rate constraints. The mathematical modeling of SVC has been presented with its incorporation procedure in conventional NR load flow. An optimal location of SVC has been identified to enhance the voltage profile in the system by minimizing the voltage deviation at system buses. The above mentioned objectives are further enhanced in the presence of SVC. The above mentioned power system problem has been tested on IEEE 14 bus system with respective validations.

REFERENCES

[1] M.A.Abido., Optimal power flow Using Tabu search Algorithm, 30:469-483,2002 Taylor and Francis 1532-5008, (2001).

[2] T. Aruldoss Albert Victoire, and A.Ebenezer Jeyakumar, Deterministically Guided PSO for dynamic dispatch considering Valve-Point Effect, Electrical. Power Systems Research, Vol.73, No.3, Pp.313-322, (2005).

[3] Guo-Lizhang, Hai-Yanlu, Geng-Yin Li, Guang-Quan Zhang, Dynamic Economic Load Dispatch Using Hybrid Genetic algorithm and the Method of Fuzzy Ranking, Proc. Of Fourth International Conf. on Machine learning and cybernetics, Guangzhou, 18-21, August (2005).

[4] T.O.Ting, M.V.C.Rao, and C.K. Loo, A novel approach for Unit Commitment problem via an effective hybrid Particle Swam Optimization, IEEE Transactions on power Systems, Vol.21, No.1, (2005).

[5] C.K. Panigrahi, P.K.Chattopadhyay, R.N.Chakrabarthi, and M.Basu, Simulated Annealing Technique for Dynamic Economic Dispatch, Electric Power Components and Systems, Vol.34, No.5, Pp.577-586, (2006).

[6] R. Chakrabarti P.K.Chattopadhyay, M.Basu, and C.K.Panigrahi, Particle Swarm Optimization Technique for Dynamic Economic Dispatch, IEI Journal –EL, Vol.87, (2006).

[7] T. Adhinarayana and M.Sydulu, Reserve Constrained Economic Dispatch with Prohibited Operating Zones Using '/- Logic' Based Algorithm, IEEE, (2007).

[8] J. G. Singh, S. N. Singh, and S. C. Srivastava, An approach for optimal placement of static VAr compensators based on reactive power spot price, IEEE Trans. Power Syst., vol. 22, no. 4, pp. 2021–2029, (2007).

[9] R. Zárate-Miñano, A. J. Conejo, and F. Milano, OPF-Based security re-dispatching including FACTS devices, IET Trans. Gen., Transm.,Distrib., vol. 2, no. 6, pp. 821–833, 2008.

[10] N. Yorino, E. E. El-Araby, H. Sasaki, and S. Harada, A new formu-lation for FACTS allocation for security enhancement against voltage collapse, IEEE Trans. Power Syst., vol. 18, no. 1, pp. 3–10, (2003).

[11] M. Eghbal, N. Yorino, E. E. El-Araby, and Y. Zoka, Multi load level reactive power planning considering slow and fast VAR devices by means of particle swarm optimization, IET Trans. Gen., Transm., Distrib., vol. 2, no. 5, pp. 743–751, (2008).

[12] R. S. Wibowo, N. Yorino, M. Eghbal, Y. Zoka, and Y. Sasaki, FACTS devices allocation for congestion management considering voltage

stability by means of MOPSO, in Proc. IEEE Transmission & Distribution Conf. Expo.: Asia and Pacific, Korea,1-4, (2009).

[13] S. Talatahari, B. Farahmand Azar, R. Sheikholeslami, A.H.Gandomi., Imperialistic competitive algorithm combined with chaos for global optimization, Commun Nonlinear Sci Numer Simulat, Vol.17, 1312-1319, (2012).

[14] http://www.ee.washington.edu/research/pstca/